Engineering Note
for
E906 Detector Assembly

PROJECT: E906

TITLE: Station 3-Minus Drift Chamber

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ABSTRACT: This document describes a drift chamber and I-beam framework which will be assembled and hung in the E906 beamline.

DESIGN:
The Station 3-Minus drift chamber was designed by the Tokyo Institute of Technology and built at Fermilab. The weight of this chamber is approximately 770 pounds. There are two steel hanger blocks attached to the top of this chamber which will be bolted to a turnbuckle and I-beam assembly shown in Figure 1. The entire package will be inserted into the beamline by resting the ends of the bottom surface of the aforementioned I-beam (type S8 x 6.35) onto the top surface of a pair of cantilevered steel I-beams that are part of an existing structure in the experimental hall.

ANALYSIS:
The drift chamber and I-beam assembly from Figure 1 will be inserted into the beamline by wrapping slings around the I-beam and using the crane in NM4. The chamber, hanger block, turnbuckle adapter, turnbuckle, I-beam, and all the fasteners must be strong enough to hang vertically for the duration of the experiment. Each of these components is analyzed separately as follows:

DRIFT CHAMBER:
The outer framework of the drift chamber consists of four (4) C-channel sections of aluminum. The section properties of this type of channel are shown in Figure 2. The alloy is 5052-H112 and the details of the channel for the side sections and the top/bottom sections are shown in Figures 3 and 4, respectively. The sides are attached to the top section using fourteen (14) M8x1 screws. The screws are made from SS304 and the load on each of these screws is 55-lbs. With a minor diameter of 0.247” (6.272mm) the stress on these bolts is 1170psi, which is acceptable for SS304. There is also a stress on the internal threads of the side c-channels. The length of engagement of the M8 screws is 0.591” (15mm) in all cases. For internal M8x1 threads this length of engagement provides a thread shear area of 0.385in^2 and the resulting shear stress of the internal threads is roughly 143psi, which is acceptable for this alloy.

When the chamber is horizontal it can be lifted at the I-beam and re-oriented to the vertical for installation in the beamline. At the start of this re-orientation the weight of the chamber is essentially borne by two side c-channels. If treated as a beams supported on both ends subject to a concentrated load at the center then the stress and deflection of these channels can be calculated using standard formulas:

Stress at center of constant cross section: $$s = \frac{-Wl}{4Z} \quad \textbf{(1)}$$

Maximum deflection at center: $$y = \frac{Wl^3}{48EI} \quad \textbf{(2)}$$

Where:
W is the weight the load (385lb)
l is the length (70.87 inches)
I is the moment of inertia (218.08-in^4)
Z is the section modulus (15.58-in^3)
E is the modulus of elasticity of 5052 aluminum (10^6 psi)

Substituting the values into equation (1) yields:

$$s = -\frac{385lb \times 70.87in}{4\left(15.58in^3\right)} = -437.8lb/in^2$$

Likewise, substituting the values into equation (2) yields:

$$y = \frac{1}{48}\left[\frac{385lb \times (70.87in)^3}{10e6psi \times 218.08in^4}\right] = 0.0013in$$

The bending stress of 437.8 psi and deflection of 0.001 inches of theses c-channel are acceptable.

When the chamber is assembled and hanging in the beamline the top c-channel will experience stress and deflection from weight of the chamber at each hanger block. If treated as a beam supported on both ends subject to concentrated identical loads equidistant from center then the stress and deflection of the c-channel can be calculated using standard formulas:

Stress at center of constant cross section: $s = \frac{-Wa}{Z}$ **(3)**

Maximum deflection at center: $y = \frac{Wa}{24EI}(3L^2 - 4a^2)$ **(4)**

Where:
- W is the weight of each load (385-lb)
- L is the length of the channel (137 inches)
- a is the distance from the end to the load (19.88 inches)
- I is the moment of inertia of c-channel beam ($27.22 in^4$)
- Z is the section modulus ($8.35 in^3$)
- E is the modulus of elasticity of 5052 aluminum (10^6 psi)

Substituting the values into equation (3) yields:

$$s = -\frac{385lb \times 19.88in}{8.35in^3} = -916.6lb/in^2$$

Likewise, substituting the values into equation (4) yields:

$$y = \frac{1}{24}\left[\frac{385lb \times (41.4in)}{10e6psi \times 27.2in^4}\right]\left[3(137.01in)^2 - 4(19.88in)^2\right] = 0.003in$$

The bending stress of 916.6 psi and deflection of 0.003 inches of the c-channels are acceptable.

Finally, when the chamber is hanging in the beamline, the ends of the top c-channel will experience a shear stress equal to the load on each end divided by cross sectional area of the c-channel. Substituting the appropriate values yields

Shear stress at ends of channel = 385lb/13.64in^2 = 28.23lb/in^2
This shear stress is acceptable for Aluminum 5052

HANGER BLOCK:
The hanger blocks are machined from solid pieces of steel (type S45C) and are attached to the drift chamber frame using eight (8) 3/8-16 bolts. See Figure 5. The load on each hanger block is 385-lbs. Therefore the load on each of the 3/8-16 bolt is 48.125-lbs. These bolts are always in shear. With a minor diameter of 0.2970" and an area of 0.069-in^2, the resulting shear stress in each 3/8-16 bolt is roughly 697.5psi. Grade 5 (alloy A325) bolts are readily available. The allowable shear for these bolts, per the Manual of Steel Construction 9th edition, is 17ksi which is far in excess of these expected actual values. These same hanger blocks are attached to the turnbuckle assembly via an adapter block using a single ¾-10 bolt, in shear. The load on each of these ¾-10 bolts is 385-lbs. With a minor diameter of 0.6255" and an area of 0.307-in^2, the resulting shear stress in each 3/4-10 bolt is roughly 1254psi which is also acceptable for Grade 5 fasteners. The ¾-10 tapped hole through the hanger block is also subjected to a tear out stress from the bolt equal to the load divided by the effective cross sectional area. The magnitude of this tear out stress, per Figure 2, is 67.78psi. Type S45C steel has yield strength of 45ksi. Assuming shear strength is 40% of yield strength results in an allowable shear of 18ksi which is also far in excess of the expected actual value.

When the chamber is hanging in the beamline the hanger block will experience stress and deflection from the weight of the drift chamber. If treated as a beam simply supported at both ends subject to a concentrated load at the center then the stress and deflection of the hanger block can be calculated using standard formulas (1) and (2) from above:

Stress at center of constant cross section: $$s = \frac{-WL}{4Z} \qquad \textbf{(1)}$$

Maximum deflection at center: $$y = \frac{WL^3}{48EI} \qquad \textbf{(2)}$$

Where:
- W is the weight of each load (385-lb)
- L is the length of the block (9.45 inches)
- I is the moment of inertia of the block (2.14in^4, per Fig. 2)
- Z is the section modulus
- E is the modulus of elasticity of S45C steel (29.1e8 psi)

Substituting the values into equation (1) yields:

$$s = -\frac{385lb \times 9.45in}{4\left(2.14in^4 \big/ 1.28in\right)} = -544.0lb/in^2$$

Likewise, substituting the values into equation (2) yields:

$$y = \frac{1}{48}\left[\frac{385lb \times (9.45in)^3}{29.1e8psi \times 2.14in^4}\right] = 0.000001in$$

The bending stress of 544.0psi and deflection of 1e-6 inches are not cause for concern.

TURNBUCKLE ADAPTER:

The turnbuckle adapters are made of type 1018 steel with yield strength of 32ksi. See Figure 6. These adapter blocks have a 0.38" diameter hole at the top to connect to the turnbuckle and a pair of 0.78" diameter holes at the bottom through which the ¾-10 bolt is inserted through the hanger block. These holes are all subjected to a tear out stress. From Figure 3, the magnitude of the stress for the 0.38" diameter hole is 575psi and that of each 0.78" hole is 158psi. Once again, assuming that shear strength is 40% of yield strength results in and allowable shear of 12.8ksi and these tear out stresses are acceptable.

TURNBUCKLE ASSEMBLY:

The turnbuckles connect the adapter block to the vertical part of the I-beam assembly. They are purchased from McMaster Carr (part number 3022T54) and have a certified work load limit of 2,200 pounds. The actual load on each turnbuckle is only 385 pounds and is well below this limit.

I-BEAM:

The I-Beam assembly is made of Aluminum type 6061. The vertical portion of the I-beam assembly is shown in Figure 7. The main component of this is a segment of S8x6.35 aluminum I-beam. A plate, 0.5 inches thick, is welded to each end of this segment and a hanger block is welded to the bottom plate. There is a 0.38" hole in the bottom of this hanger block that is connected to the turnbuckle. The load on this hole is 385 pounds and the tear out stress is 726psi. The yield shear strength of this alloy is 20ksi and the tear out stress of 726psi is acceptable. The other end of this block is welded to the endplate, all around, with a fillet weld. The weld has a leg size of $^3/_{16}$-inch which corresponds to a throat of 0.133". The effective throat area of this weld is 0.632in^2 and the 385 pound load results in a shear of 609psi. The filler material is ER4043 and the allowable shear for this type of weld (Aluminum Design Manual, Part VI, 2010) is 5.9ksi which is well in excess of the expected actual value. The endplates are similarly welded to the web of the I-beam on each side. The throat of these welds is also 0.133" and the total length of both welds is 17.3" giving an effective throat area of 2.30in^2. This leads to a shear of 167psi which is also acceptable for this type of weld.

The vertical portions of the I-beam assembly are attached to a long aluminum I beam using four (4) 3/8-16 bolts. See Figure 1, Detail B. The load on each connection is 385-lbs. Therefore the load on each of the 3/8-16 bolts is 96.25-lbs. These bolts are always in tension. With a tensile stress area of 0.0774-in^2 each of these bolts experience a tensile stress of 1244psi. The allowable tension for these bolts, per the Manual of Steel Construction 9th edition, is 44ksi which is far in excess of these expected actual values. The 385 pound load also creates tension in the vertical I-beam segments. The cross sectional area of the S8 I-beam is 5.4in^2 and the resulting tension is 71.3psi which is acceptable for Type 6061 aluminum.

When lifting the chamber from the horizontal position to the vertical position (or lowering from vertical to horizontal), the I-Beam assembly must be positioned directly over the hanger blocks on the chamber in order to prevent a horizontal load from being applied to the vertical S8 columns. As the chamber orientation changes it will be necessary to reposition the crane in order to maintain this condition.

The chamber assembly will be inserted into the beam line by resting the ends of the bottom surface of the aluminum I-beam onto the top surface of a pair of cantilevered steel I-beams that beams that are part of an existing structure in the experimental hall. Once in place this aluminum I-beam will experience stress and deflection from the weight of the drift chamber. If treated as a beam supported on both ends subject to concentrated identical loads equidistant from center then the stress and deflection of the I-beam can be calculated using formulas **(3)** and **(4)** from above:

Stress at center of constant cross section: $s = \frac{-Wa}{Z}$ **(3)**

Maximum deflection at center: $y = \frac{Wa}{24EI}(3L^2 - 4a^2)$ **(4)**

Where:
- W is the weight of each load (385-lb)
- L is the length of the beam(180 inches)
- a is the distance from the end to the load (41.4 inches)
- I is the moment of inertia of S8x6.35 beam (57.6in^4)
- Z is the section modulus
- E is the modulus of elasticity of 6061 aluminum

Substituting the values into equation (3) yields:

$$s = -\frac{385lb \times 41.4in}{\left(57.6in^4 / 4in\right)} = -1106.9lb/in^2$$

Likewise, substituting the values into equation (4) yields:

$$y = \frac{1}{24}\left[\frac{385lb \times (41.4in)}{10e6psi \times 57.6in^4}\right]\left[3(180in)^2 - 4(41.4in)^2\right] = 0.104in$$

The bending stress of 1106.9 psi and deflection of 0.104-in of the S8x6.35 I-beam are acceptable.

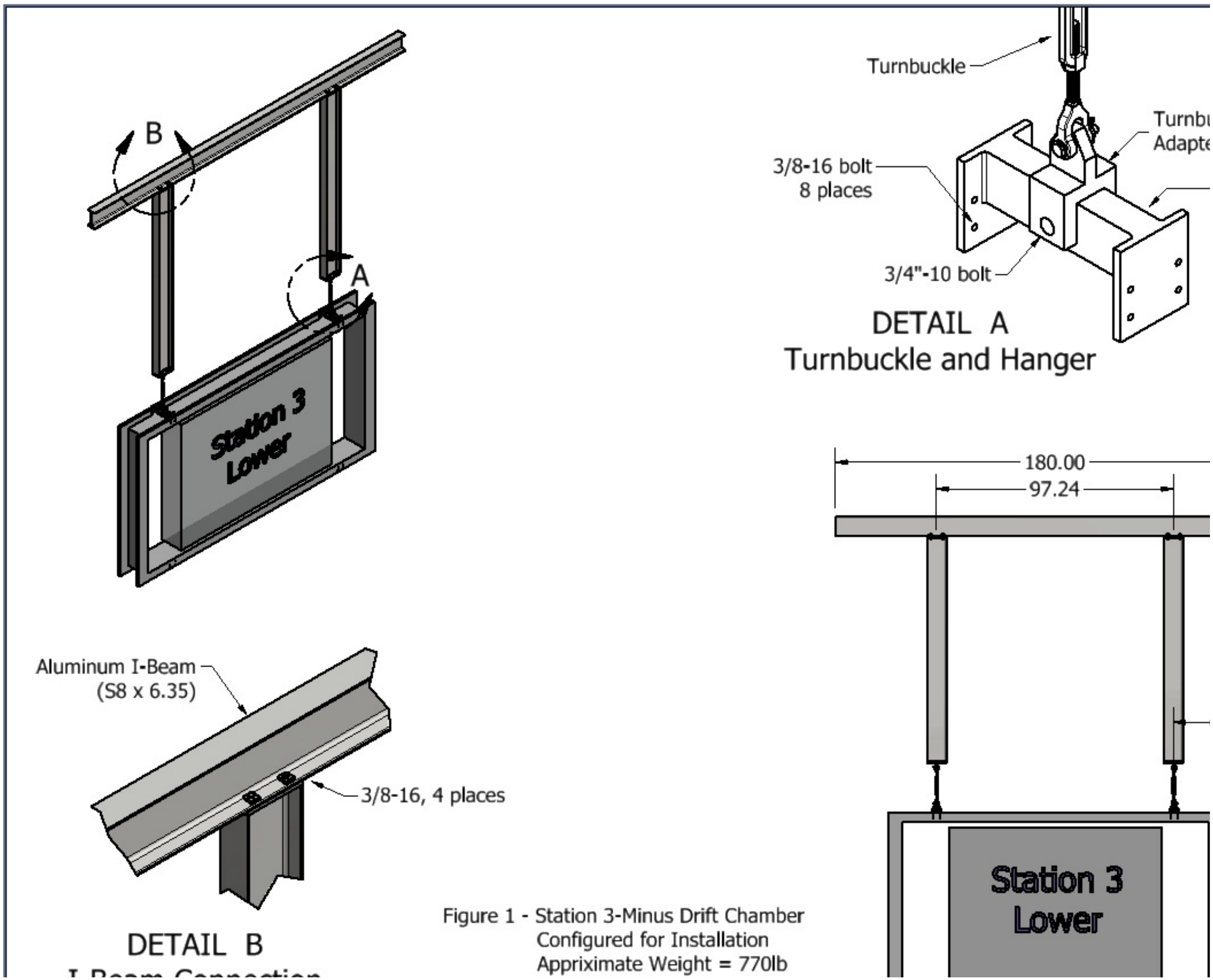
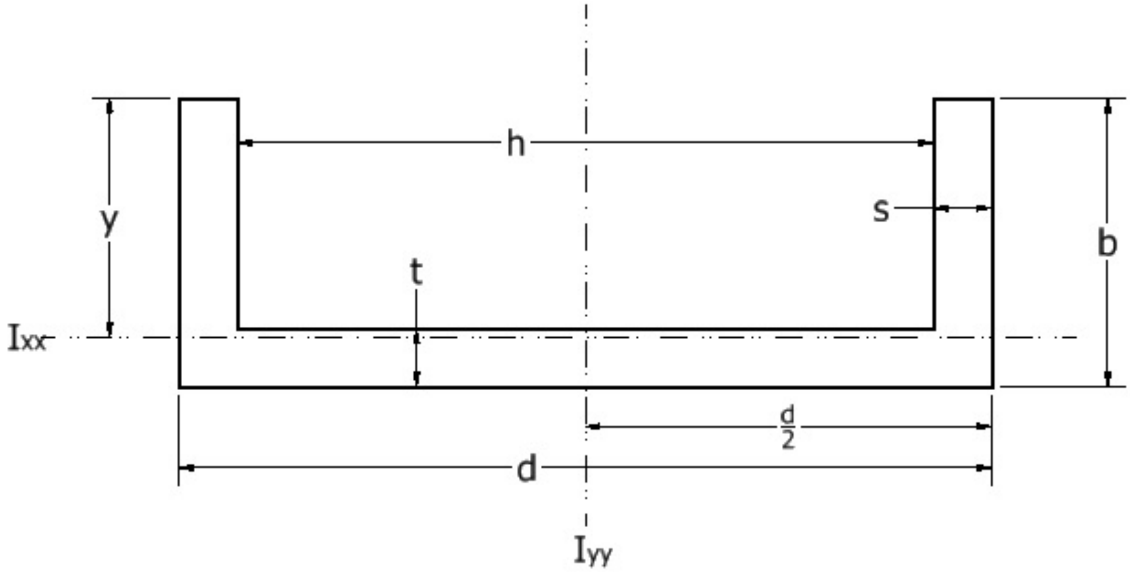


Figure 1 - Station 3-Minus Drift Chamber
Configured for Installation
Appriximate Weight = 770lb



<u>CROSS SECTION AREA</u>: $A = bd - h(b - t)$

<u>ALONG THE XX DIRECTION</u>:

Distance to Neutral Axis: $y \quad = b - \frac{2b^2 s + ht^2}{2bd - 2h(b-t)}$

Moment of Inertia: $I_{xx} \quad = \frac{2sb^3 + ht^3}{3} - A(b - y)^2$

Section Modulus: $Z_x \quad = \frac{I_{xx}}{y}$

<u>ALONG THE YY DIRECTION</u>:

Distance to Neutral Axis: $d/2$

Moment of Inertia: $I_{yy} \quad = \frac{bd^3 - h^3(b-t)}{12}$

Section Modulus: $Z_y \quad = \frac{I_{yy}}{d/2}$

Figure 2 – Section Properties of Rectangular C-Channel

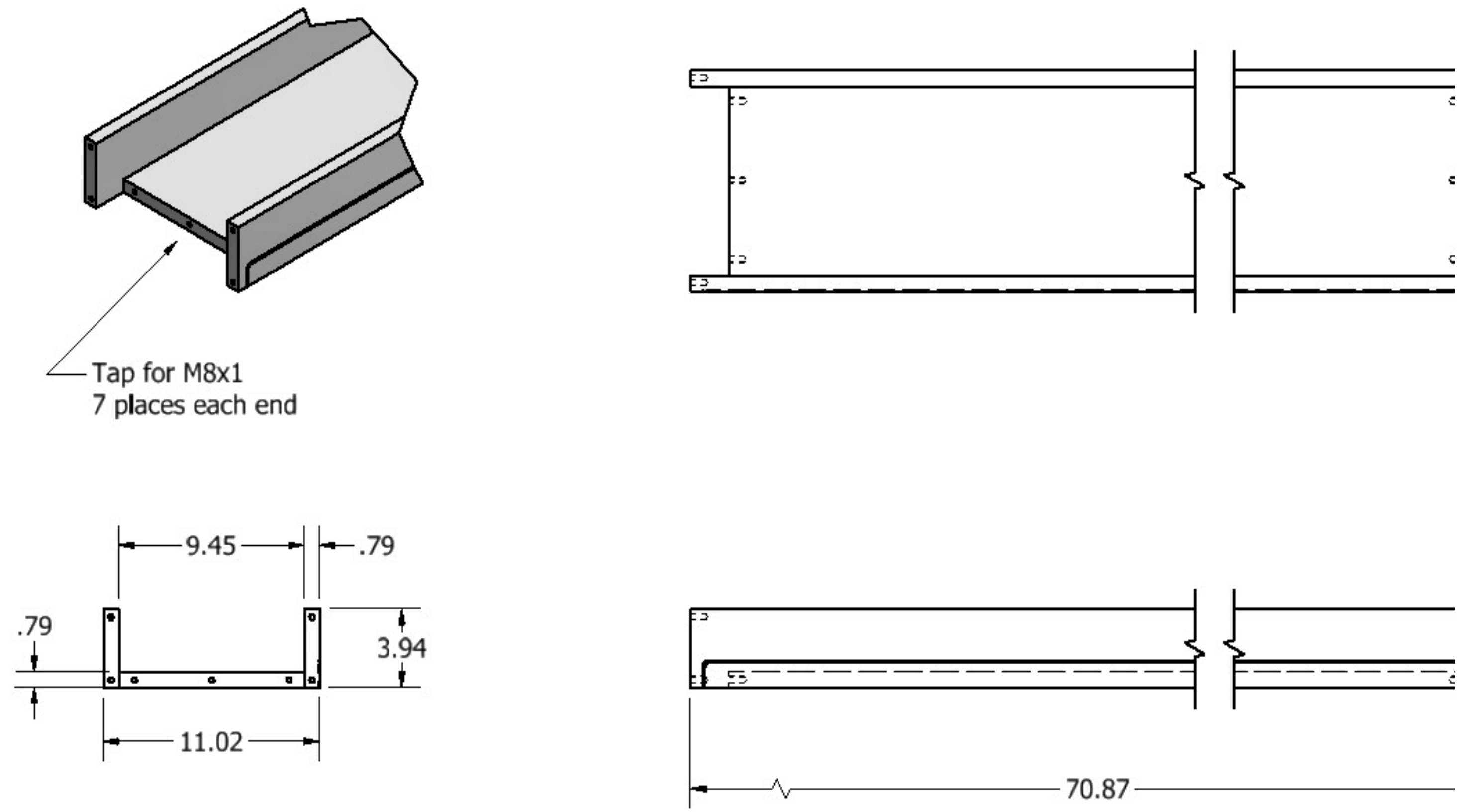


Figure 3 - C-Channel for Station 3 Drift Chambers (Side Section)

Aluminum 5052

Yield Strength = 17.4ksi (per Tokyo Institute of Technology)

E_{mod} = 10e6psi

Moment of Inertia = 218.08in^4

Cross Sectional Area = 13.64in^2

Section Modulus = 15.58in^3

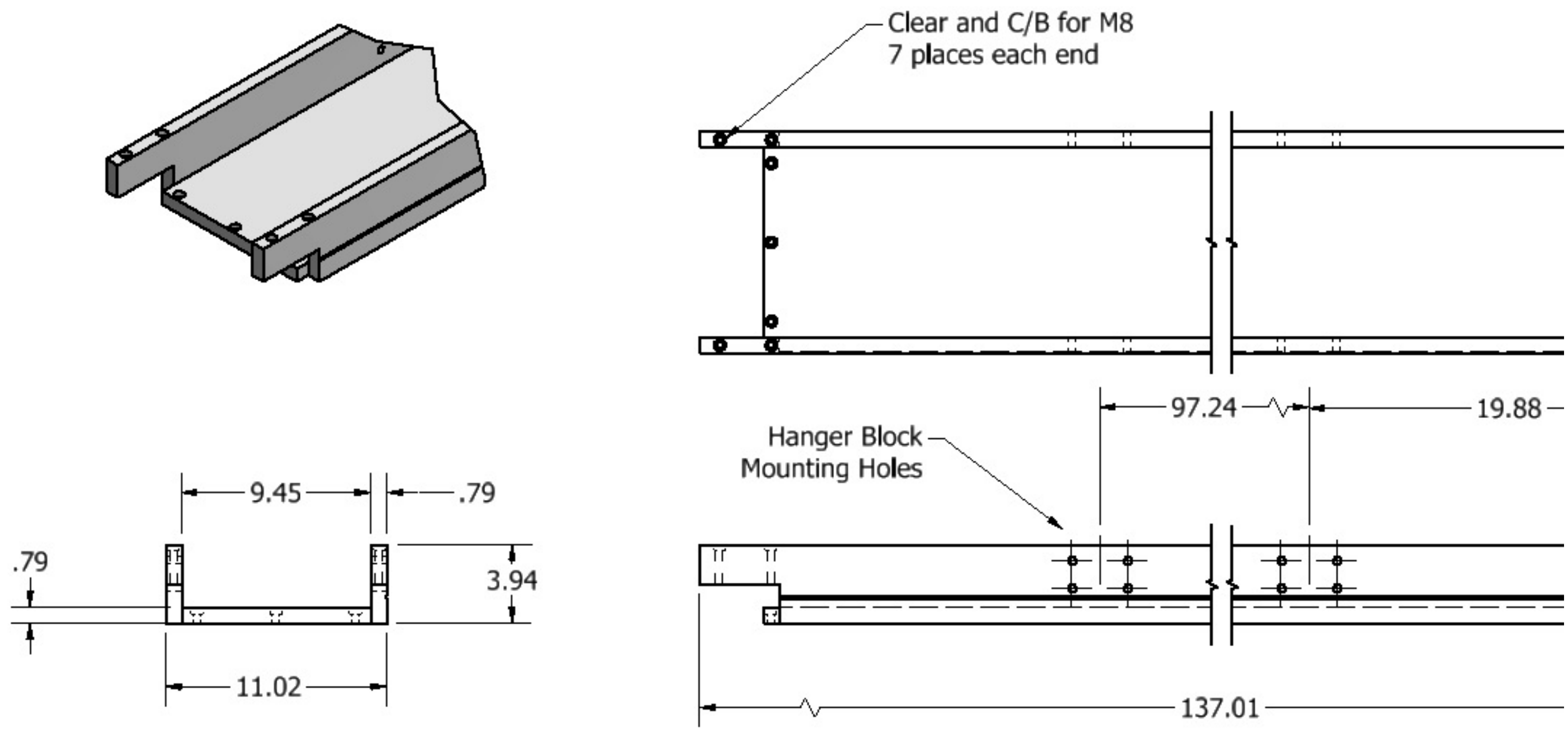
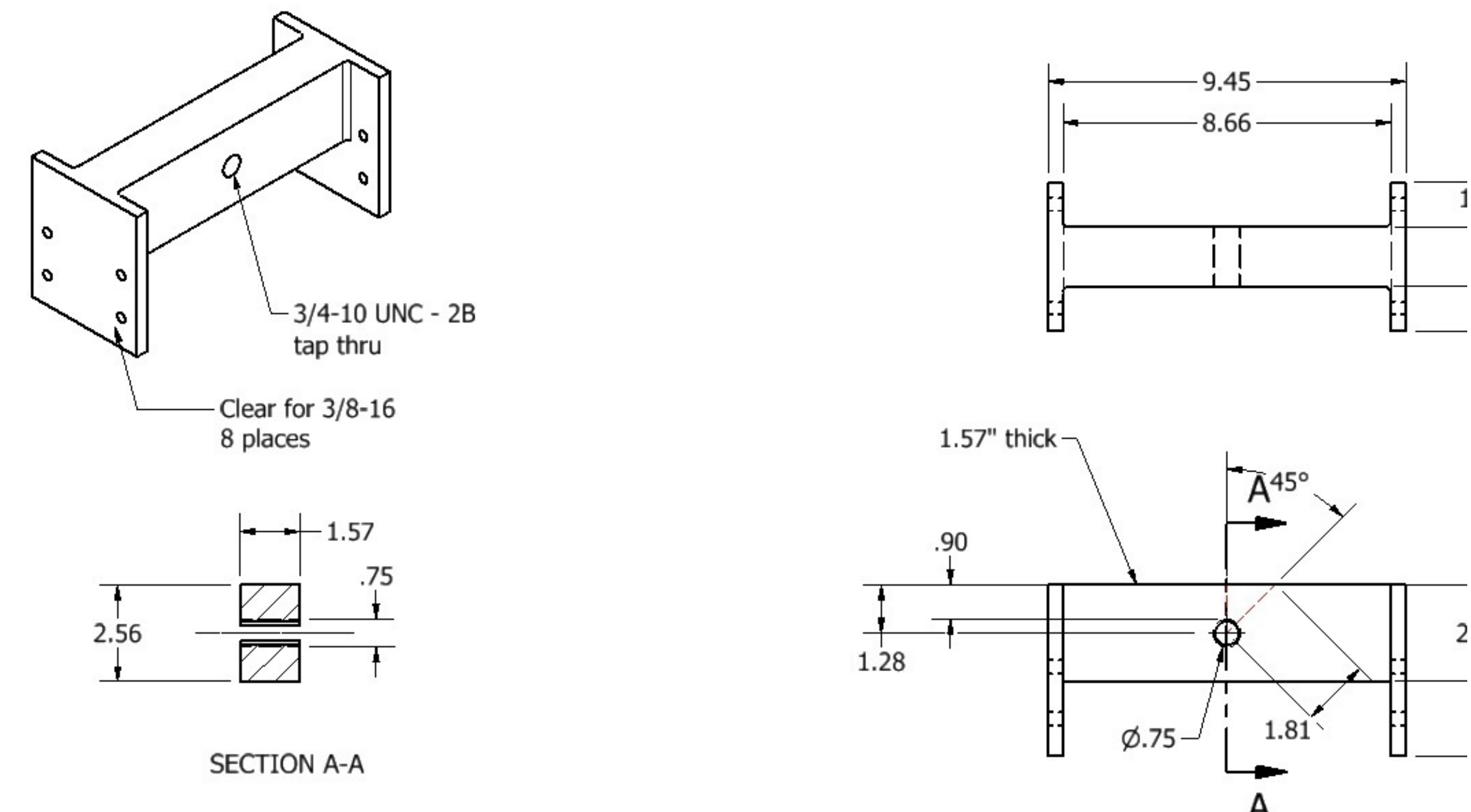


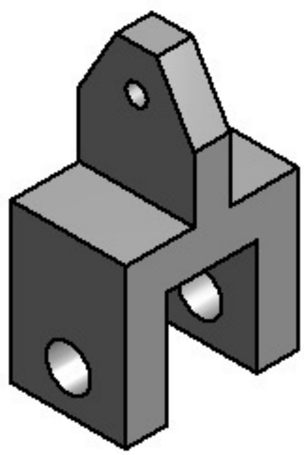
Figure 4 - C-Channel for Station 3 Drift Chambers (Top Section)
Aluminum 5052
Yield Strength = 17.4ksi (per Tokyo Institute of Technology)
E_{mod} = 10e6psi
Moment of Inertia = 27.22in^4



Moment of Inertia*
Through the center of the tapped hole -
$I = 1.57(2.56^3 - 0.75^3)/12$
$= 2.14\text{-in}^4$
*Manual of Steel Construction, 9th Edition

Hole Tearout Analysis:
Load on 3/4-10 tapped hole = 385 pounds
Effective Cross Sectional Area:
A = 2(1.81)(1.57)
= 5.68-in^2
Shear on hole = 385/5.68 = 67.78psi

Figure 5 - Hanger Block, Steel S45C
Ultimate Tensile Strength = 81.9ksi, Yield Strength = 45ksi, E-mod = 29.1e8 psi
Allowable Shear = 0.4(45ksi) = 18ksi per Manual of Steel Construction, 9th Ed.



Hole Tearout Analysis:

Load on Ø.38 thru hole = 385 pounds

Effective Cross Sectional Area:

$A = 2(0.53)(0.63)$
$= 0.67\text{-in}^2$

Shear on hole = 385/0.67 = 574.63psi

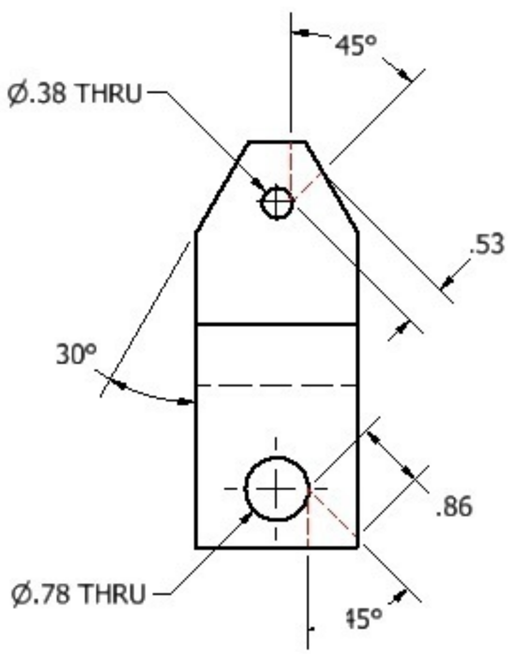
Hole Tearout Analysis:

Load on each Ø.78 thru hole = 193 pounds

Effective Cross Sectional Area:

$A = 2(0.86)(0.71)$
$= 1.22\text{-in}^2$

Shear on hole = 193/1.22 = 158.20psi



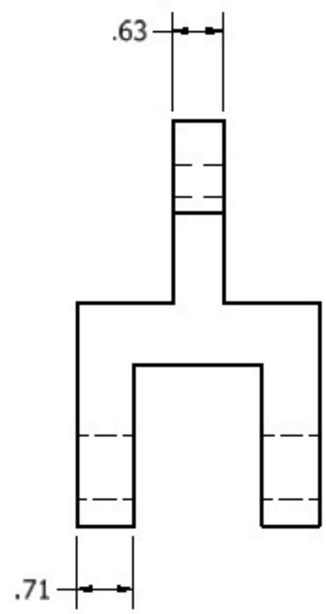
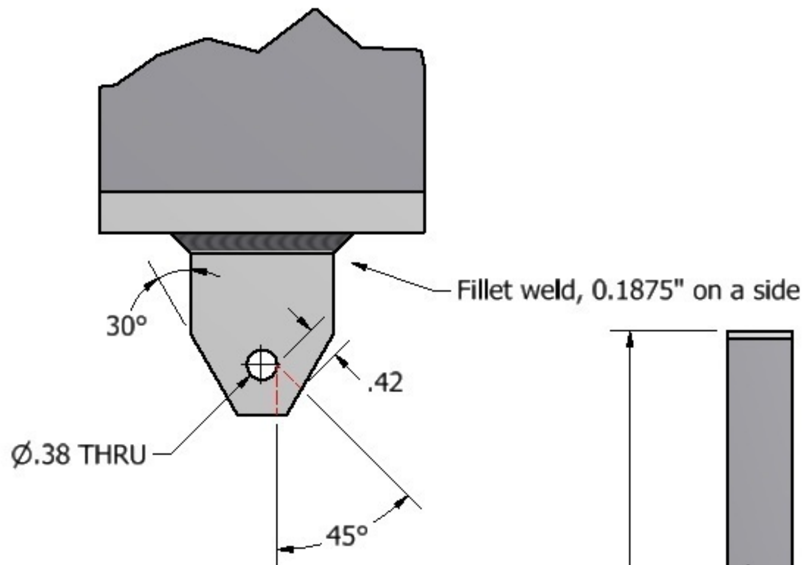
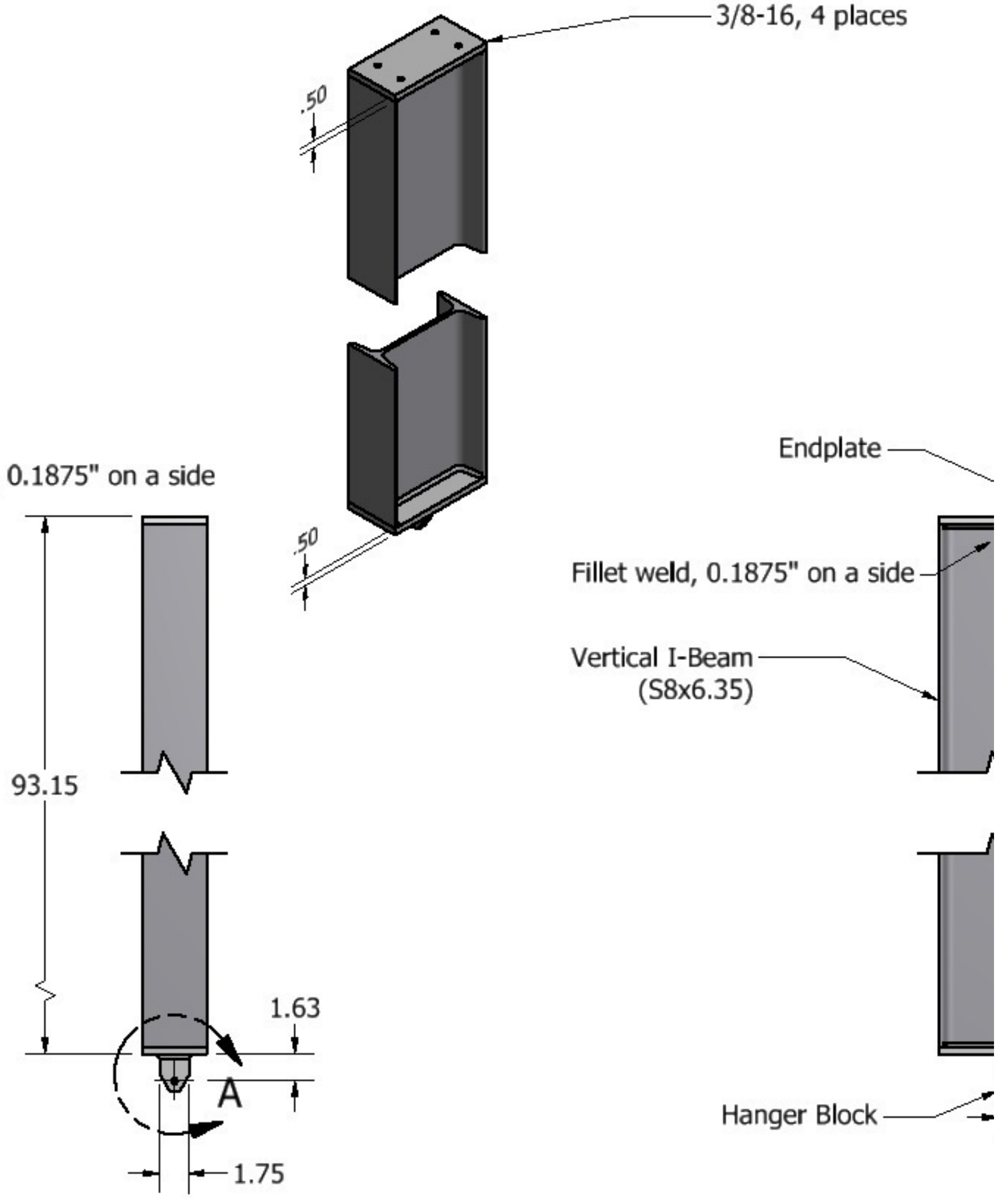


Figure 6 - Turnbuckle Adapter, Steel 1018

Ultimate Tensile Strength = 58ksi, Yield Strength = 32ksi

Allowable Shear = 0.4(32) = 12.89.9ksi





Hole Tearout Analysis:

Load on Ø.38 thru hole = 385 pounds

Effective Cross Sectional Area:

A = 2(0.42)(0.63)

= 0.53-in^2

Shear on hole = 385/0.53 = 726.42psi